# Appendix A. Methodology for Estimating HFC and PFC Emissions from Substitution of Ozone Depleting Substances

## A. Overview

The Vintaging Model was developed as a tool for estimating the annual chemical emissions from industrial sectors that have historically used ozone-depleting substances (ODS) in their products. Under the terms of the Montreal Protocol and the Clean Air Act Amendments of 1990, the domestic production of ODS – chloroflourocarbons (CFCs), halons, carbon tetrachloride, methyl chloroforms, and hydrochlorofluorocarbons (HCFCs) – has been drastically reduced, forcing these industrial sectors to transition to more ozone friendly chemicals. As these industries have moved toward ODS alternatives such as hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs), the Vintaging model has evolved into a tool for estimating the rise in consumption and emissions of these alternatives, and the fall of ODS consumption and emissions.

The Vintaging model, named for its method of tracking the emissions of annual "vintages" of new equipment that enter into service, is a "bottom-up" model. It models use and emissions of chemicals based on estimates of the quantity of equipment or products sold each year containing these chemicals, and the amount of chemical required to manufacture and/or maintain equipment and products over time. As ODS are phased out, a percentage of the market share originally occupied by the ODS is allocated to each of its substitutes.

The model estimates emissions from six end-use categories: refrigeration and air-conditioning, foams, aerosols, solvents, fire extinguishing, and sterilization. Within these categories, there are over 40 independently modeled end-uses. The model requires input regarding the market growth for each of the end-uses, as well a history of the market transition from ODS to alternatives. For the purpose of projecting the use and emissions of chemicals into the future, the model incorporates the available information about probable evolutions of the end-use market.

The Vintaging model makes use of this market information to build an inventory of the in-use stocks of the equipment in each of the end-uses. This includes the percentage of the equipment stock that contains each chemical. These modeled stock inventories are maintained through the annual addition of new equipment and the retirement of equipment after an appropriate number of years. Annual leak rates, servicing emissions, and disposal emissions are estimated for each of the end-uses. It is through these emissions, occurring throughout the lifetime of the equipment, that the lag between consumption of chemical and actual emission of chemical is created. By aggregating the emission and consumption output over the different end-uses, the model produces estimates of total annual use and emissions of each chemical.

The Vintaging Model synthesizes data from a variety of sources, including data from the ODS Tracking System maintained by the Stratospheric Protection Division and information from submissions to EPA under the Significant New Alternatives Policy (SNAP) program. Published sources include documents prepared by the United Nations Environment Programme (UNEP) Technical Options Committees, reports from the Alternative Fluorocarbons Environmental Acceptability Study (AFEAS), and conference proceedings from the International Conferences on Ozone Protection Technologies. EPA also coordinates extensively with numerous trade associations and individual companies. For example, the Alliance for Responsible Atmospheric Policy, the Air-Conditioning and Refrigeration Institute, the Association of Home Appliance Manufacturers, the American Automobile Manufacturers Association, and many of their member companies, have provided valuable information over the years. In some instances the unpublished information that the EPA uses in the model is classified as Confidential Business Information (CBI). While in most cases the annual emissions inventories and projections of chemicals are aggregated in such a way that CBI cannot be inferred, there are times when additional aggregation is necessary to protect sensitive data. Full public disclosure of the inputs to the Vintaging model would jeopardize the security of the CBI that has been entrusted to the EPA.

Within the context of the Cost of Emissions Reductions Analysis, the Vintaging model was used exclusively to project the emissions reductions that could be expected from the mitigation techniques outlined in the body of the report. These projected reductions were then used to create the marginal abatement curves also contained in the body of the report. Two types of projections are necessary to calculate the reductions: "baseline" emissions and model scenarios that reflect the proposed mitigation techniques. A "baseline" is a measure of the emissions that would be expected if no mitigation techniques were to enter into practice. Reductions are defined as the difference between these two projections.

The following sections discuss the forms of the emission estimating equations used in the Vintaging model for each broad end-use category.

# B. Emission Equations

## Refrigeration and Air-Conditioning

For refrigeration and air conditioning products, emission calculations are split into two categories: emissions during equipment lifetime, which arise from annual leakage and service losses, and disposal emissions, which occur at the time of discard. For each year, the model tracks which vintages are in use, which are being discarded, how much of each chemical is being recycled, what chemicals are in each vintage, and at what rates these chemicals are emitted. Equation 1 calculates the lifetime emissions from leakage and service, and Equation 2 calculates the emissions resulting from disposal of the equipment. These lifetime emissions and disposal emissions are summed across each vintage to establish the total emissions from refrigeration and air-conditioning for a given year (Equation 3). As new technologies replace older ones, it is generally assumed that there are improvements in their leak, service, and disposal emission rates.

Lifetime emissions from any piece of equipment include both the amount of chemical leaked during equipment operation and during service recharges. Emissions during emissions from leakage and servicing can be expressed as follows:

$$E_{ES} = U_{ES} * C_{ES} * (LR_{ES} + SR_{ES}) * PC_{ES} \qquad \text{Eq. 1}$$

Where:

$E_{ES}$ = *Emissions from Equipment Serviced*. Emissions from a specific chemical in a given year from equipment leaks and service (recharging) for a particular type of refrigeration equipment.

$U_{ES}$ = *Units of Equipment in Service*. Number of equipment units in service in a given year for a particular type of refrigeration equipment.

$C_{ES}$ = *Charge of Equipment in Service*. Average charge of a specific chemical for equipment units in service in a given year, in Kg. Equal to the average charge when equipment units were newly manufactured.

$LR_{ES}$ = *Leak Rate of Equipment in Service*. Annual average leak rate as a percent of the average charge of a specific chemical for equipment units in service in a given year for a particular type of refrigeration equipment.

$SR_{ES}$ = *Service Rate of Equipment in Service*. Average emissions at service (amount of charge lost) as a percent of the average charge of a specific chemical for equipment units in service in a given year for a particular type of refrigeration equipment.

$PC_{ES}$ = *Penetration of Chemical in Equipment in Service*. Amount of a specific chemical as a percentage of all chemicals used in equipment units in service in a given year for a particular type of refrigeration equipment. In other words, this is the market penetration, in percent terms, of any ODS substitute in a given end-use.

The disposal emission equations assume that a certain percentage of the chemical consumed in a particular year will be emitted to the atmosphere when that vintage is discarded. Disposal emissions are thus a function of the number of units being disposed and the proportion of chemical released at disposal:

$$E_{ED} = U_{ED} * C_{ED} * PC_{ED} * [1 - (CR_{ED} * CRR_{ED})]$$

Eq. 2

Where:

$E_{ED}$ = *Emissions from Equipment Disposed*. Emissions of a specific chemical in a given year from equipment disposal, for a particular type of refrigeration equipment.

$U_{ED}$ = *Units of Equipment Disposed.* Number of equipment units being retired in a given year for a particular type of refrigeration operation.

$C_{ED}$ = *Charge of Equipment Disposed.* Average charge of a specific chemical for equipment units being retired in a given year by weight. Equal to the average charge when equipment units were newly manufactured.

$PC_{ED}$ = *Penetration of Chemical in Equipment Disposed.* Amount of a specific chemical, as a percentage of all chemicals used in equipment units being retired, in a given year for a particular type of refrigeration equipment.

$CR_{ED}$ = *Chemical Remaining*. Amount of a specific chemical remaining in equipment units being retired in a given year, as a percentage of the average charge size, for a particular type of refrigeration equipment.

$CRR_{ED}$= *Chemical Recovery Rate*. Percent of chemical recovered from equipment being retired as a percentage of chemical remaining, for a particular type of refrigeration equipment in a given year.

$$E_T = E_{ES} + E_{ED}$$

Eq. 3

Where:

$E_T$ = *Total Emissions*. Emissions of a specific chemical in a given year for a particular type of refrigeration equipment.

$E_{ES}$ = *Emissions from Equipment Serviced*. Emissions from a specific chemical in a given year from equipment leaks and service (recharging) for a particular type of refrigeration equipment.

$E_{ED}$ = *Emissions from Equipment Disposed*. Emissions of a specific chemical in a given year from equipment disposal for a particular type of refrigeration equipment.

## Aerosols

All HFCs and PFCs used in aerosols are assumed emitted in the year of manufacture. Since there is currently no aerosol recycling, it is assumed that all of the annual production of aerosol propellants is released to the atmosphere. Equation 4 describes the emissions from the aerosols sector.

$$E = QC$$

Eq. 4

Where:

E = *Emissions*. Total emissions of a specific chemical in a given year from use in aerosol products, by weight

QC = *Quantity of Chemical*. Total quantity of a specific chemical contained in aerosol products sold in the given year, by weight

## Solvents

Generally, most solvents used are assumed to remain in the liquid phase and are not emitted as gas. Thus, emissions are considered "incomplete," and are set as a fraction of the amount of solvent consumed in a year. For solvent applications, a fixed percentage of the new chemical used in equipment is assumed emitted in that year. The remainder of the used solvent is assumed to be reused or disposed without being released to the atmosphere. Equation 5 calculates emissions from solvent applications.

$$E = \mathrm{L} * QC \qquad \text{Eq. 5}$$

Where:

E = *Emissions*. Total emissions of a specific chemical in a given year from use in solvent applications, by weight.

L = *Percent Leakage*. The percentage of the total chemical that is leaked to the atmosphere.

QC = *Quantity of Chemical*. Total quantity of a specific chemical sold for use in solvent applications in the given year, by weight.

## Fire Extinguishing

Total emissions from fire extinguishing are assumed, in aggregate, to equal a percentage of the total quantity of chemical in operation at a given time. For modeling purposes, it is assumed that fire extinguishing equipment leaks at a constant rate for an average equipment lifetime. This percentage varies for streaming (Equation 6) and flooding (Equation 7) equipment.

### (i) Streaming Equipment

$$E = \mathrm{L} * \Sigma QC_i \quad \text{For } i = (j\text{-}x) \text{ to } j \qquad \text{Eq. 6}$$

Where:

$x$ = The average lifetime of the equipment.

$j$ = Index of the given year.

E = *Emissions*. Total emissions of a specific chemical in a given year for streaming fire extinguishing equipment, by weight.

L = *Percent Leakage*. The percentage of the total chemical in operation that is leaked to the atmosphere.

QC = *Quantity of Chemical.* Total amount of a specific chemical used in new streaming fire extinguishing equipment in a given year, *j*, by weight.

$\Sigma QC_i$ = *Sum of Quantity of Chemical over Multiple Years.* Total amount of a specific chemical used in new streaming fire extinguishing equipment from year (*j*-15) to year *j*, by weight.

### (ii) Flooding Equipment

$$E = \mathrm{L} * \Sigma QC_i \quad \text{For } i = (j\text{-}x) \text{ to } j \qquad \text{Eq. 7}$$

Where:

$x$ = The average lifetime of the equipment.

$j$ = Index of the given year.

E = *Emissions*. Total emissions of a specific chemical in a given year for flooding fire extinguishing equipment, by weight.

L = *Percent Leakage*. The percentage of the total chemical in operation that is leaked to the atmosphere.

QC = *Quantity of Chemical.* Total amount of a specific chemical used in new flooding fire extinguishing equipment in a given year, *j*, by weight.

$\Sigma QC_i$ = *Sum of Quantity of Chemical over Multiple Years.* Total amount of a specific chemical used in new flooding fire extinguishing equipment from year (*j*-15) to year *j*, by weight.

## Foam Blowing

Foams are given emission profiles depending on the foam type (open cell or closed cell). Emissions for open cell foams are assumed to be 100 percent in the year of manufacture (Equation 8). Closed cell foams were assumed to emit a portion of total HFC or PFC use upon manufacture, a portion at a constant rate over the lifetime of the foam, and a portion at disposal (Equation 9).

### (i) Open-Cell Foam

$$E = QC$$

Eq. 8

Where:

E = *Emissions*. Total emissions of a specific chemical in a given year for open-cell foam blowing, in metric tons.

QC = *Quantity of Chemical.* Total amount of a specific chemical used for open-cell foam blowing in the same given year, in metric tons.

### (ii) Closed-Cell Foam

$$E = \Sigma \, (EF_i * QC_i) \quad \text{Where, } i = (j\text{-}x) \text{ to } j \text{, and } x = \text{foam lifetime}$$

Eq. 9

Where:

*j* = Index of the given year.

E = *Emissions*. Total emissions of a specific chemical in a given year for closed-cell foam blowing, by weight.

EF = *Emission Factor*. Percent of foam's original charge emitted in year j. This emission factor is generally variable, with a separate value for manufacturing, lifetime, and disposal emissions.

QC = *Quantity of Chemical.* Total amount of a specific chemical used in closed-cell foams manufactured in a given year, *j*.

## Sterilization

For sterilization applications, all chemicals that are used in the equipment in any given year are assumed to be emitted in that year, as shown in Equation 10.

$$E = QC$$

Eq. 10

Where:

E = *Emissions*. Total emissions of a specific chemical in a given year from use in sterilization equipment, by weight.

QC = *Quantity of Chemical.* Total quantity of a specific chemical contained in sterilization equipment used in the same given year, by weight.

# C. Model Output

By repeating these calculations from the years 1985-2030, the Vintaging model creates annual profiles of use and emissions for ODS and ODS substitutes. The results can be shown for each year in two ways: 1) on a chemical-by-chemical basis, summed across the end-uses, or, 2) on an end-use basis. Values for use and emissions are calculated both in metric tons and in million metric tons of carbon equivalents (MMTCE). The conversion of metric tons of chemical to MMTCE is accomplished through a linear scaling of tonnage by the global warming potential (GWP) of each chemical. The GWP values that are used in the model correspond to those published in the IPCC Third Assessment Report.

Throughout its development, the Vintaging model has undergone annual modifications. As new or more accurate information becomes available, the model is adjusted in such a way that both its projections and its hindcasts are often altered.

For further clarification, additional documents or other information please write to:

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